

Convective and Lightning Initiation Nowcasting Research using Geostationary Satellite towards Enhancing Aviation Safety

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Supported by:

NASA New Investigator Program (2002)
NASA ASAP Initiative
The NASA SPoRT & SERVIR Initiatives

Collaborators:

University of Wisconsin-Madison, CIMSS
MIT-Lincoln Laboratory
NASA MSFC
USRA

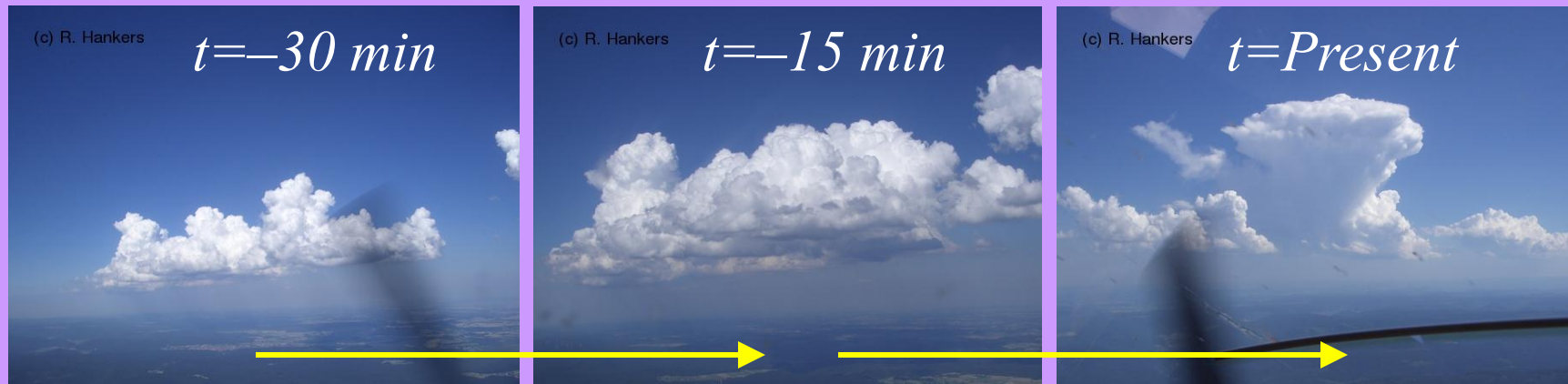


Methods: *Convective Nowcasts/Diagnoses*

Why might geostationary satellite be superior to radar?

A: Satellites “see” cumulus before they become thunderstorms!

A: There are many available methods for diagnosing/monitoring cumulus motion/development in real-time (every 15-min). See the published research.



Monitor... 8 IR fields:

CI Time →

1st $\geq 35 \text{ dBZ}$ echo
at ground



SATCAST Algorithm: *GOES IR Interest Fields*

<u>CI Interest Field</u>	<u>Purpose and Resolution</u>	<u>MB06 Critical Value</u>
6.5 \checkmark 10.7 μm difference (IF1)	4 km cloud-top height relative to upper-tropospheric WV weighting function (Schmetz et al. 1997)	$\checkmark 5_i \text{ C to } \checkmark 10_i \text{ C}$
13.3 \checkmark 10.7 μm difference (IF2)	8 km cloud-top height assessment (Mecikalski and Bedka 2006; Mecikalski et al. 2008)	$\checkmark 25_i \text{ C to } \checkmark 5_i \text{ C}$
10.7 μm T_B (IF3)	4 km cloud-top glaciation (Roberts and Rutledge 2003)	$-20_i \text{ C} < T_B < 0_i \text{ C}$
10.7 μm T_B Drop Below 0_i C (IF4)	4 km cloud-top glaciation (Roberts and Rutledge 2003)	Within prior 30 mins
10.7 μm T_B Time Trend (IF5, IF6)	4 km cloud-top growth rate/updraft strength (Roberts and Rutledge 2003)	$< \checkmark 4_i \text{ C/15 mins}$ $\Delta T_B/30 \text{ mins} < \Delta T_B/15 \text{ mins}$
6.5 \checkmark 10.7 μm Time Trend (IF7)	4 km multi-spectral cloud growth (Mecikalski and Bedka 2006)	$> 3_i \text{ C/15 mins}$
13.3 \checkmark 10.7 μm Time Trend (IF8)	8 km multi-spectral cloud growth (Mecikalski and Bedka 2006; Mecikalski et al. 2008)	$> 3_i \text{ C/15 mins}$

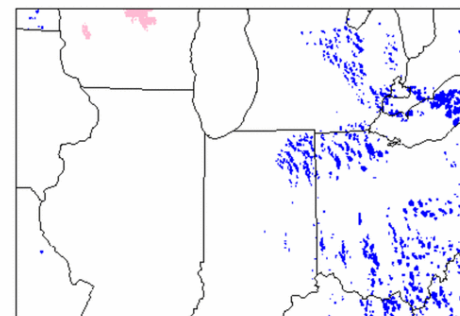
Note: There are several more IR fields with MSG & MTG

SATCAST Capabilities

- 0-1 hour CI nowcasting
- 0-90 min Lightning Initiation nowcasting
- Satellite climatologies for daily forecasts
- 1-6 hour CI/LI forecasting support
- Data assimilation possibilities

Satellite data valid at: 2215 UTC 3 September 2005

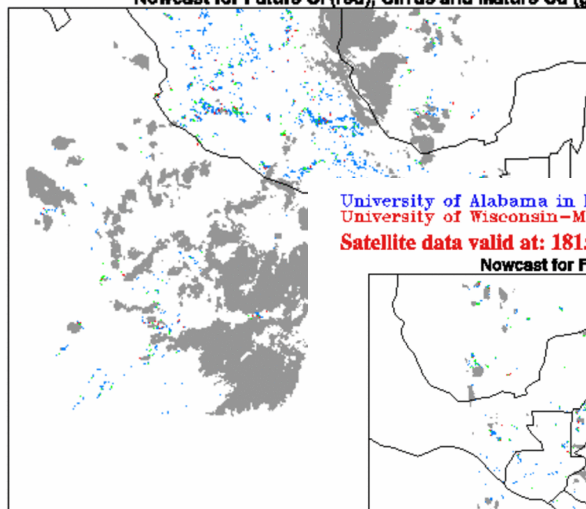
Convective Cloud Mask



University of Alabama in Huntsville (UAH)
University of Wisconsin-Madison, CIMSS

Satellite data valid at: 1915 UTC 3 September 2005

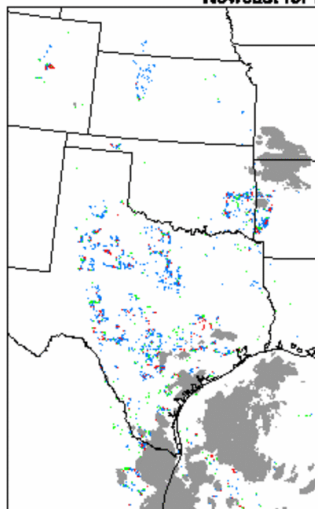
Nowcast for Future CI (red), Cirrus and Mature Cu (grey)



University of Alabama in Huntsville (UAH)
University of Wisconsin-Madison, CIMSS

Satellite data valid at: 2031 UTC 3 September 2005

Nowcast for



(3-4 of 8) blue

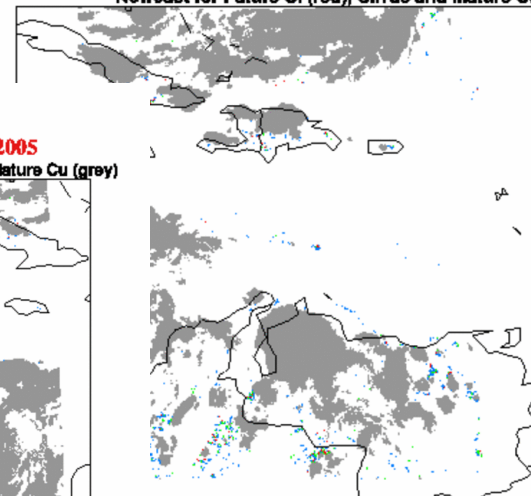
(5-6 of 8) green

(7-8 of 8) red

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Satellite data valid at: 2015 UTC 3 September 2005

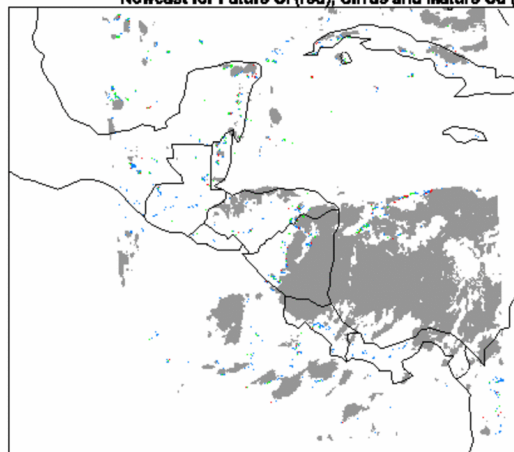
Nowcast for Future CI (red), Cirrus and Mature Cu (grey)



University of Alabama in Huntsville (UAH)
University of Wisconsin-Madison, CIMSS

Satellite data valid at: 1815 UTC 3 September 2005

Nowcast for Future CI (red), Cirrus and Mature Cu (grey)



Good CI detection in Cloudy Environment

MIT-Lincoln Lab: CoSPA testing

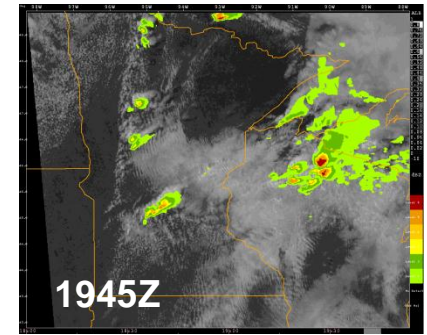
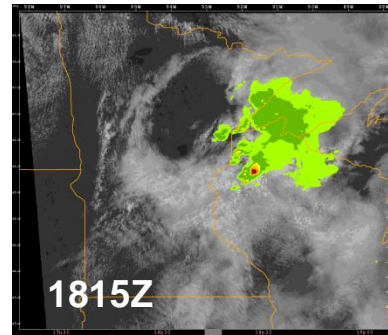
- Using convective initiation to predict storms:

- Location – CI score

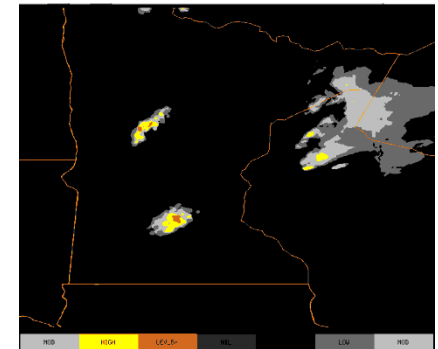
➡ – **Timing** – how long until VIL reaches CI threshold

- Mode – line or cell

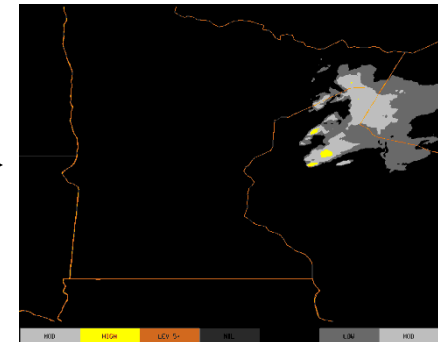
➡ – **Growth** – predict growth of cells



90-min VIL Forecast
with satellite CI ➡



90-min VIL Forecast
without satellite CI ➡



SATCAST Strengths/Weaknesses

Strengths:

- Lead time on the radar for CI ~10-45 min (up to 75 min at night)
- Provide an alert for first-time LI of up to 1 hour
- There is promise for heavy rainfall (QPE) nowcasting
- It exploits GEO satellite in the ways it was designed for, namely frequent updates (5-15 min) visible and infrared data
- Readily expandable to new instruments/methods
- Monitors cloud growth and associated microphysical changes

Areas for Improvement:

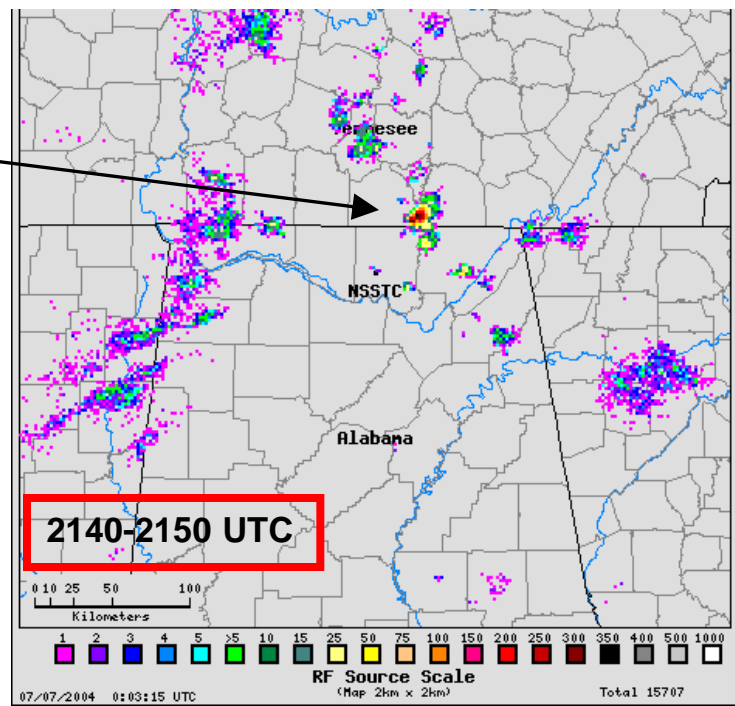
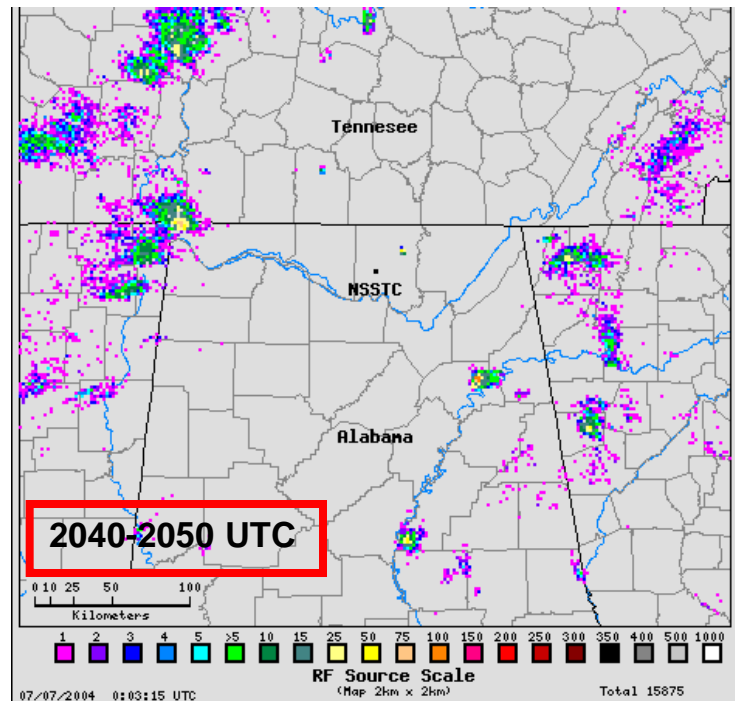
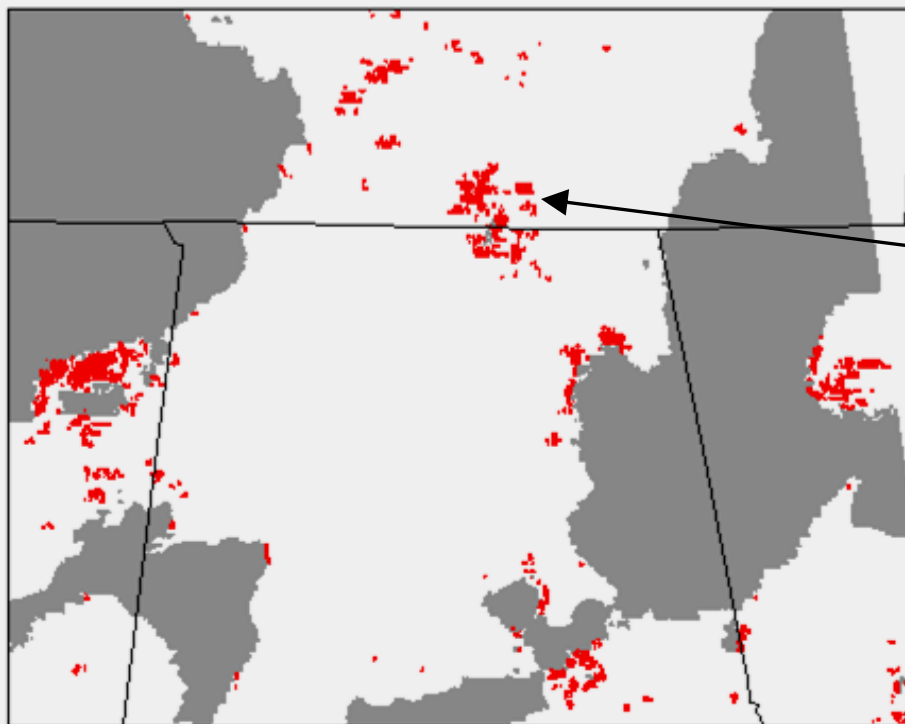
- PODs are very high (>95%) for CI, but so are FARs (~65%)
- SATCAST monitors *only* cloud-top properties
- Other non-satellite fields are needed to “constrain” SATCAST nowcasts of CI, LI and rainfall
- Little convective environment delineators, presently

Outstanding Questions: *New Research*

- How many interest fields are “important” when performing 0-1 hour nowcasting?
- What fields are more important, and which fields are most important in: (a) particular environments, and (b) across environments?
- How to constrain satellite CI nowcasts?
- Understanding how satellite IR data relate to the physics of cumulus convection, and then, *appropriately* use the satellite data.
- Minimizing errors: Better tracking & detection of cumuli.

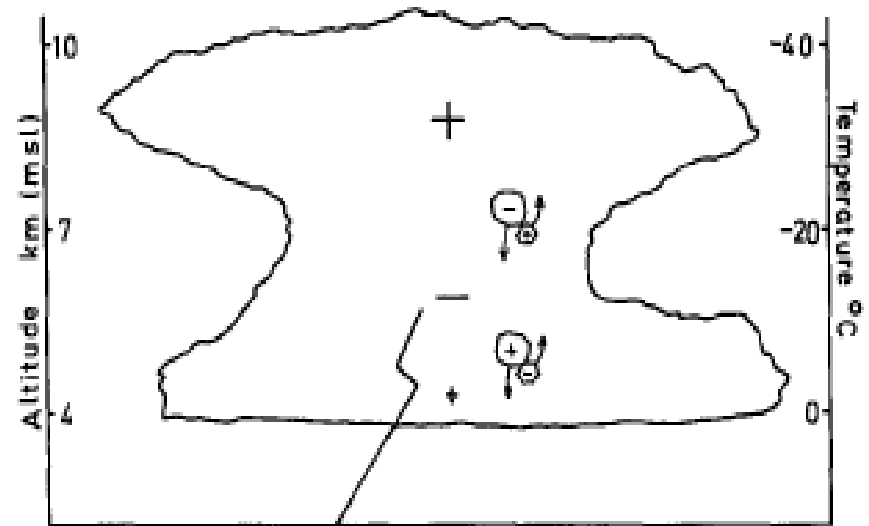
Lightning Initiation Potential

Satellite data valid at: 2045 UTC 6 July 2004
Nowcast for Future CI (red), Cirrus and Mature Cu (grey)



LI Theory

- Storm Electrification
 - Through graupel/ice interactions in the presence of supercooled water (non-inductive charge transfer, Reynolds 1957)
 - Particle collisions transfer charge
 - Temperature difference between particles and liquid water content determines charge transferred
 - Particles fall through or are carried upward in updraft and separate charge
 - Conditions to be observed from satellite:
 - Strong updraft
 - Ice particles
 - NWP model information:
 - CAPE
 - Ice/graupel flux through -10 to -15 C layer



Saunders (1993)



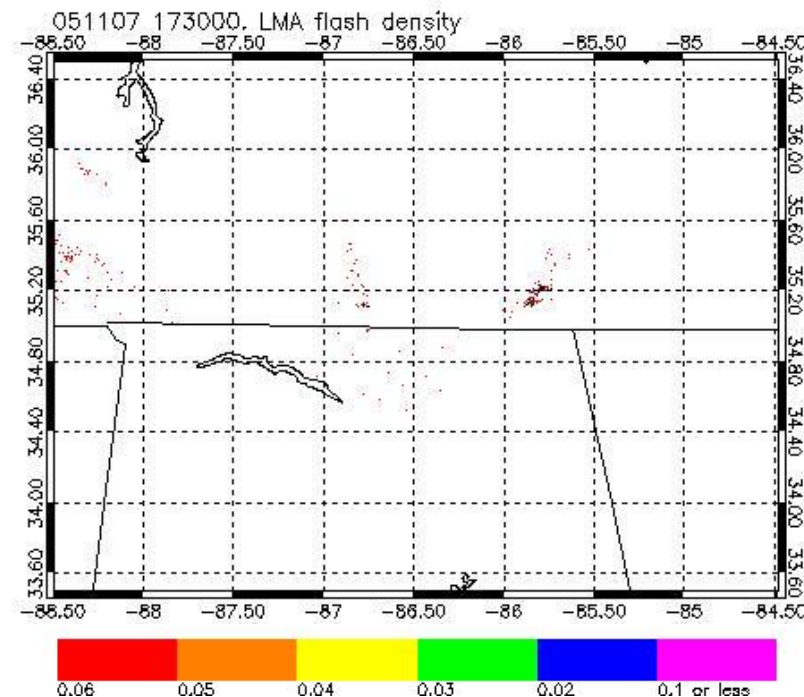
Daytime Cloud Microphysics: 3.9 μm

- Separate 3.9 reflection and emission
 - Uses methods developed by Setvak and Doswell (1991) and Lindsey et al. (2006)
 - Low 3.9 reflectance values indicate ice aloft
 - Most accurate for solar zenith angles up to 68° (morning to evening): Undefined $> 90^\circ$
 - Expect 3.9 reflectance values ~ 0.05 (5%) for ice clouds

$$\alpha_{3.9} = \frac{R_{3.9} - R_{e_{3.9}}(T)}{S - R_{e_{3.9}}(T)}$$

$$R = \text{fk1} / [\exp (\text{fk2} / (\text{bc1} + (\text{bc2} * \text{temp}))) - 1]$$

- $R_{3.9}$ calculated using 3.9 brightness temperature and constants
- $R_{e_{3.9}}(T)$ calculated using 3.9 constants and 10.7 brightness temperature
- S calculated using 3.9 constants, sun temperature (5800 K), average radius of sun (A) and Earth's orbit (B), and solar zenith angle



3.9 μm Reflectance Calculation

- Need to convert brightness temperatures back to radiances:

$$R = \frac{FK1}{\left[e^{\left(\frac{FK2}{(BC1 + (BC2 * T))} \right)} - 1 \right]}$$

Constant	Value
FK1	0.20096 x 10 ⁶
FK2	0.36902 x 10 ⁴
BC1	0.69703
BC2	0.99902

Provided by ASPB & CIMSS Calibration Homepage

- Now separate components...

3.9 μm Reflectance Calculation

$$R_{3.9} = R_{r_{3.9}} + \varepsilon_{3.9} R_{e_{3.9}}(T), \quad (1)$$

$$R_{r_{3.9}} = \alpha_{3.9} \left[R_{e_{3.9}}(T_{\text{sun}}) \left(\frac{A}{B} \right)^2 \cos(\phi) \right], \quad (2)$$

S

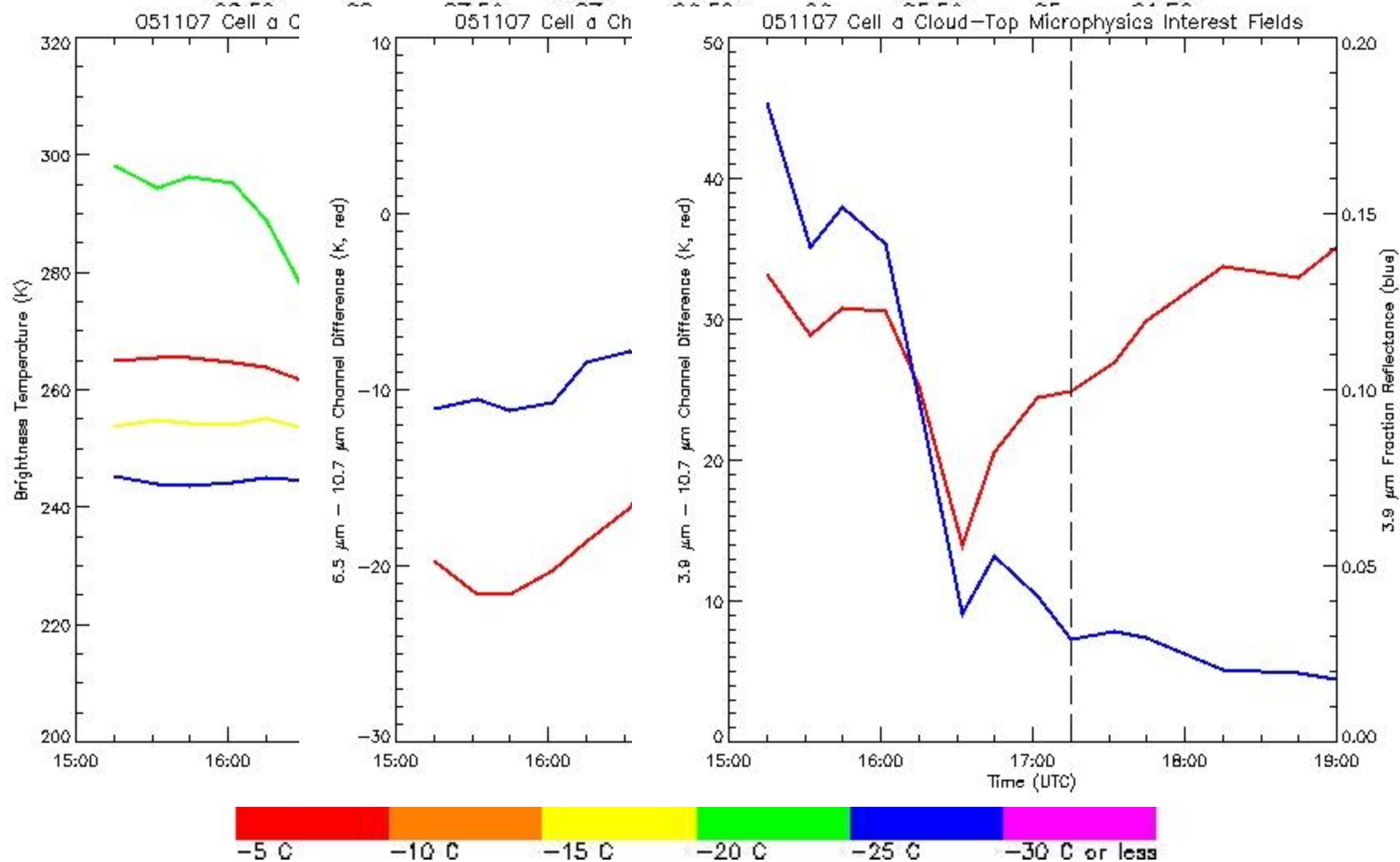
$$\varepsilon_{3.9} + \alpha_{3.9} = 1. \quad (3)$$

$$\alpha_{3.9} = \frac{R_{3.9} - R_{e_{3.9}}(T)}{S - R_{e_{3.9}}(T)}. \quad (4)$$

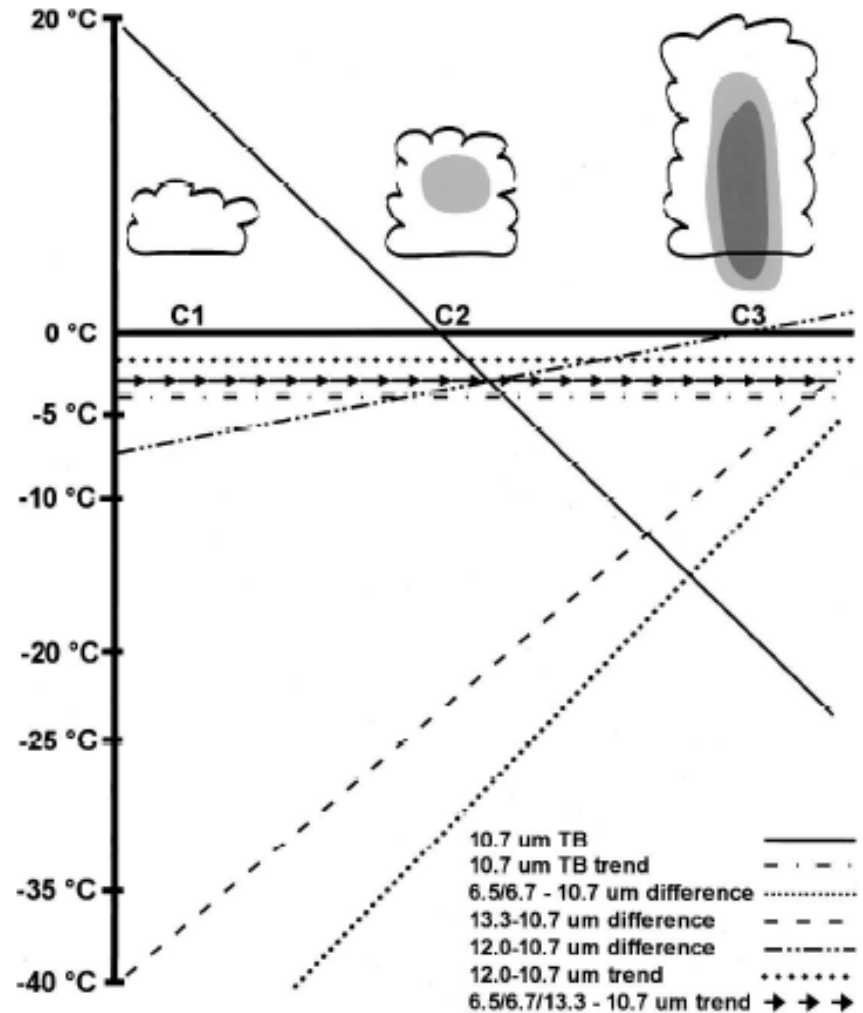
Development of LI Interest Fields

- **Co-location of satellite and LMA data**
 - Satellite data re-sampled to 1 km² grid
 - LMA has slightly smaller grid (~ 0.9 km²)
 - Match the satellite data to an LMA pixel using nearest neighbor technique with latitude and longitude values
- **Time-series plot analysis**
 - Examine multiple cells from various case days
 - Allows for visual representation of interest fields with time in comparison to first flash within the cell
 - Isolate cell by drawing box around its movement area prior to and after the first flash.
 - Follow coldest pixel(s) in this box (assumed updraft region)
 - Average the brightness temperature values of these coldest pixels for all channels and perform channel differences
 - Plot values 2 hours prior and 1 hour after the first flash within the cell
 - Compare to expected results and define appropriate initial threshold values for LI interest fields

051107 174500. 10.7 μm cloud top temperature

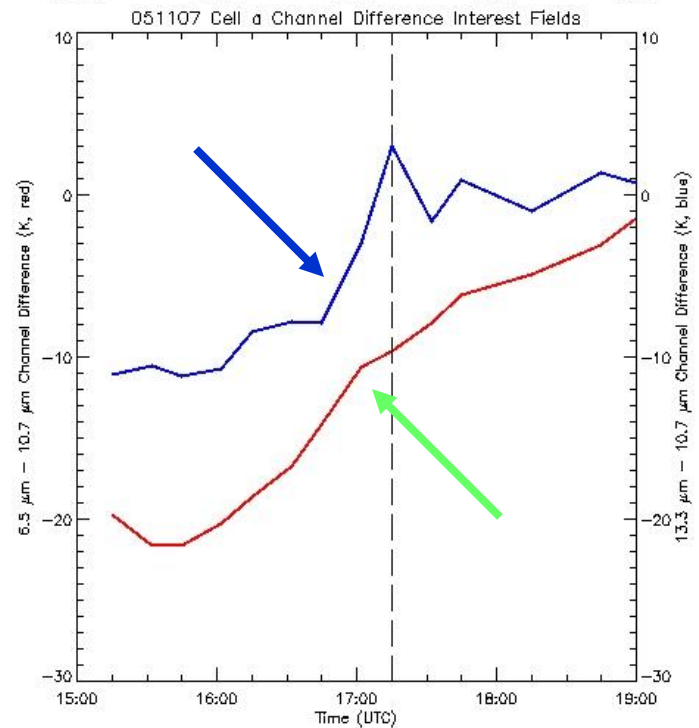
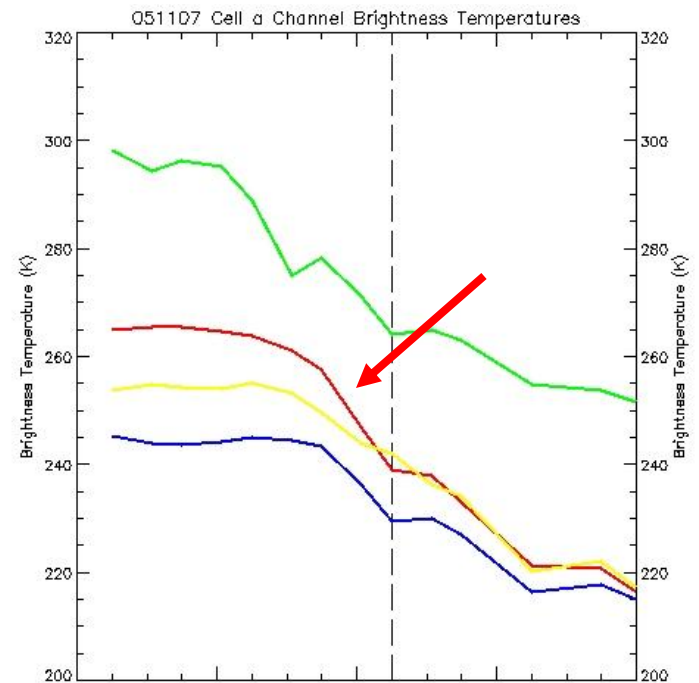
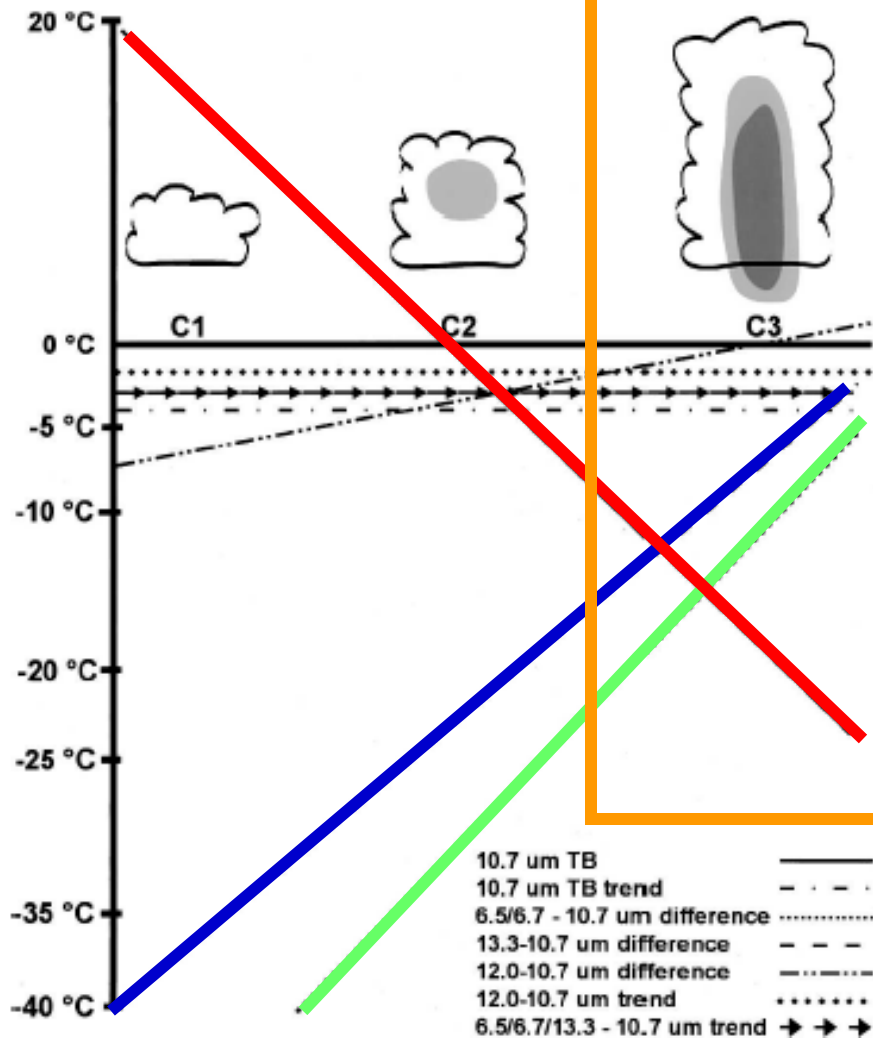


- Mecikalski and Bedka (2006) framework:
 - Forecast location of first 35 dBZ echo using eight CI “interest fields”
 - Each interest field represents physical process within growing cloud
 - Individual pixel must meet at least 7 of 8 field thresholds to be labeled a “threat” of CI



Mecikalski and Bedka (2006)

LI interest period



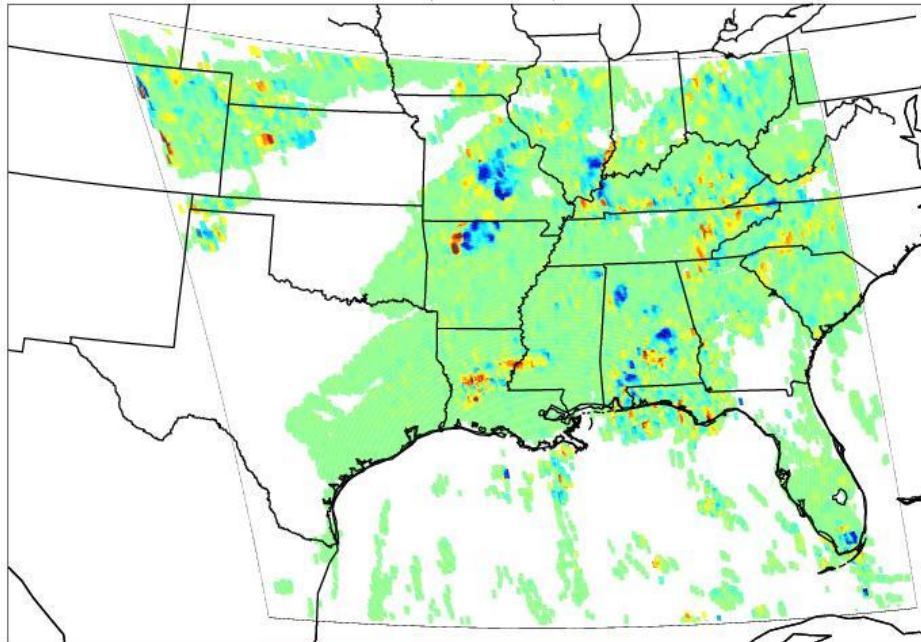
Lightning Initiation Interest Fields

LI Interest Field	Threshold Value
$10.7 \mu\text{m } T_B$	$\leq 260 \text{ K}$
$10.7 \mu\text{m } 15 \text{ minute trend}$	$\leq -10 \text{ K}$
$10.7 \mu\text{m } 30 \text{ minute trend}$	$\leq -15 \text{ K}$
$6.5 - 10.7 \mu\text{m channel difference}$	$\geq -17 \text{ K}$
$6.5 - 10.7 \mu\text{m } 15 \text{ minute trend}$	$\geq 5 \text{ K}$
$13.3 - 10.7 \mu\text{m channel difference}$	$\geq -7 \text{ K}$
$13.3 - 10.7 \mu\text{m } 15 \text{ minute trend}$	$\geq 5 \text{ K}$
$3.9 \mu\text{m fraction reflectance}$	≤ 0.05
$3.9 - 10.7 \mu\text{m trend}$	$t - (t_{-1}) \leq -5 \text{ K and } t - (t_{+1}) \leq -5 \text{ K}$

1-6 hour CI Nowcasting

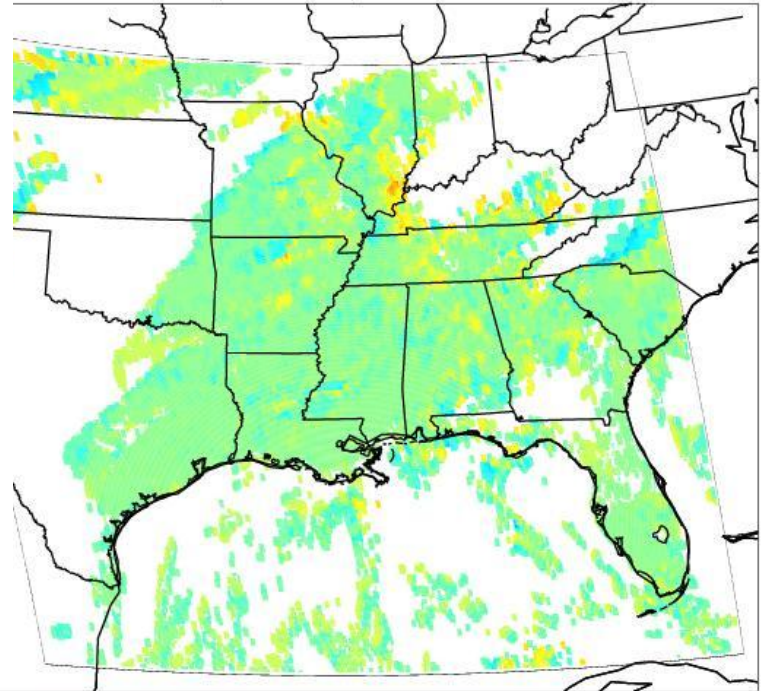
CI “Trends of Trends” - for LI eventually

Satellite data valid at: 1815 UTC 09-22-2006 (mm-dd-yyyy)
60 Minute Trend of 15 min Cloud-Top Cooling Rate (to 1815)
Based on current and previous 3 CI product times



-1 0 1
15 min CTC Rate Change (normalized)

Valid at: 1815 UTC 09-22-2006 (mm-dd-yyyy)
60 Minute Trend of CI Score (to 1815)
Based on current and previous 3 CI product times



-8 -6 -4 -2 0 2 4 6 8
CI Score Change

Ongoing Work with SATCAST

- Evaluating use of MSG (as a proxy for ABI) for enhancing SATCAST with additional interest fields, especially related to microphysics

- Perform new work with CloudSAT & MODIS to enhance SATCAST for various convective regimes

- Transition to FAA nowcasting system

- Bound SATCAST with various other NWP model fields to better bound the CI & LI nowcasts

- Determine the feasibility of making 1-4 km QPE nowcasts using this system

Table 1: Summary of visible and infrared channels data that the MSG SERVIRI and MTG FCI and IRS instruments can provide for CI and LI nowcasting (0-1 h forecasting). Here, “HRV” is “high-resolution visible data. See text for descriptions on how these channels may be specifically used in the MB06 algorithm. The new MTG channels, above those from MSG, are highlighted in grey.

	Channels for CI and LI Nowcasting
MSG	HRV, 0.8, 1.6, 3.8, 6.2, 7.3, 8.7, 10.8, 12.0 and 13.4 μm
MTG	HRV, 0.444, 0.96, 1.375, 1.6, 2.26, 3.8, 6.2, 7.3, 8.7, 10.5, 12.0 and 13.4 μm ; IRS-retrieved soundings of temperature and moisture.

Onward to MTG... post MSG (GOES-R)

**COPS
data
analysis
ongoing**

<u>CI Interest Field</u>	<u>Critical Value</u>	<u>Physical Interpretation & Comments</u>
[1] 10.8 μm T_B [IF1]	$< 0_i$ C	Cloud-top coldness
[2] 10.8 μm T_B Time Trend [IF2, IF3]	$< \tilde{G}_i$ C/15 mins $\Delta T_B/30 \text{ min} < \Delta T_B/15 \text{ min}$	Cloud growth rates
[1] 10.8 μm T_B drop to $< 0_i$ C [IF4]	Within prior 30 mins	Cloud-top glaciation
[1] 6.2 \tilde{G} 10.8 μm difference [IF5]	$\tilde{G} 0_i$ C to $\tilde{G} 0_i$ C	Cloud growth into dry air aloft
[1] 6.2 \tilde{G} 10.8 μm Time Trend [IF6]	$> 2\text{-}3_i$ C/15 mins	Cloud growth rates into dry air aloft
[2] 13.4 \tilde{G} 10.8 μm difference [IF7] 12.0 \tilde{G} 10.8 μm difference	$\tilde{G} 25_i$ C to $\tilde{G} 1_i$ C 0 to $\tilde{G} 1_i$ C	Cloud growth information, into mid- and upper troposphere (redundant)
[2] 13.4 \tilde{G} 10.8 μm Trend [IF8] 12.0 \tilde{G} 10.8 μm Trend	$> 3_i$ C/15 mins $> 1_i$ C/15 mins	Cloud growth rate information, into mid- and upper- troposphere (redundant)
[1] 3.9 \tilde{G} 10.8 μm difference [IF9]	Transition across 0_i C in 15-30 min	Cloud-top glaciation (see also Lensky and Rosenfeld 2008)
[1] 3.9 \tilde{G} 10.8 μm Time Trend [IF10]	$> -5 _i$ C	Cloud-top glaciation (see also Lensky and Rosenfeld 2008)
[1] 7.3 \tilde{G} 10.8 μm difference [IF11]	$\tilde{G} 40_i$ C to $\tilde{G} 15_i$ C	Cloud growth into dry air aloft (may be redundant with 6.2 \tilde{G} 10.8 μm)
[1] 7.3 \tilde{G} 10.8 μm Time Trend [IF12]	$> 3\text{-}4_i$ C/15 mins	Cloud growth rates into dry air aloft (may be redundant with 6.2 \tilde{G} 10.8 μm)
[1] 1.6 \tilde{G} 0.8 μm difference [IF13]	Look-up table for microphysics and glaciation (0-1)	Cloud-top glaciation (daytime only)
[1] 1.6 \tilde{G} 0.8 μm Time Trend [IF14]	Positive trend towards +1	Cloud-top glaciation rates (daytime only)
[1] 8.7 \tilde{G} 10.8 μm difference [IF15] 8.7 \tilde{G} 12.0 μm difference	Look-up table for microphysics; $< 0_i$ C (use existing product)	Cloud-top glaciation towards precipitation formation
[1] 8.7 \tilde{G} 10.8 μm Time Trend [IF16]	-2-5 $_i$ C/15 min	Cloud-top glaciation rates towards precipitation formation
[1] 6.2 \tilde{G} 7.3 μm difference [IF17]	Positive difference	Assessing if cumulus broke capping inversion
[19] CI Indicators		

MSG satellite related IR interest field that were preliminarily evaluated for use within the MB06 algorithm. A total of 19 possible indicators were considered. See text for description of each indicator

Ongoing Satellite-Lightning Research

- **NSF:** Relating lightning initiation (LI) to polarimetric radar and (geostationary) satellite fields. Several topics...~2-3 graduate students/post-Doc. *Into 2011.*
- **NASA ROSES 2007:** Optimizing the SATCAST algorithm for convective regimes, and extending to LI across various convective environments. *Into 2010.*
- **NASA ASAP:** Developments of LI nowcasts and products towards aviation sector.
- **Overall:** How to constrain satellite CI and LI nowcasts with NWP information. Enhance the lightning threat product.
- **Minimizing errors:** Better tracking & detection of cumuli.